

ULTRAVIOLET SPECTROSCOPY OF OLD NOVAE AND SYMBIOTIC STARS

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ABSTRACT

Low-dispersion, short-wavelength IUE spectra are presented for two old novae, DQ Herculis (1934) and V603 Aquilae (1918) = HD 174107, and for two symbiotic variables, AG Pegasi = HD 207757 and CI Cygni. The emission line spectra of the novae are relatively sparse, dominated by a strong C IV ($\lambda 1549$) feature and showing weaker emissions arising from NV ($\lambda 1241$), Si IV + O IV] ($\lambda \lambda 1398, 1402$), and He II ($\lambda 1640$). The absence of intercombination lines suggest electron densities greater than 10^{10} cm^{-3} . The continua of the two novae are remarkably different, the appearance seemingly dictated by the inclination of the system. The symbiotic variables display a more variegated emission line spectrum, exhibiting features of O I ($\lambda 1304$), N IV] ($\lambda 1485$), N III] ($\lambda 1752$), and C III] ($\lambda 1909$). The continua for the quiescent symbiotics are stellar in appearance and change as a function of the system inclination. These results confirm the existence of hot companions in the symbiotic stars, lending support to the binary hypothesis for these variables. Model atmospheres are fit to the spectra to estimate the properties of the hot components.

INTRODUCTION

Ultraviolet spectra have been obtained for several old novae and various of the symbiotic stars in order to study the nature of these objects in a region inaccessible to ground-based observations. The ultraviolet data are being combined with optical spectra in order to provide absolute flux distributions extending into the near infrared.

In order to ascertain the steady-state post-eruptive properties of these active systems, the data were obtained while the stars were in their quiescent states. Hence, the observations can be compared directly with various of the steady-state models that have been proposed to explain the novae and nova-like variables.

The old novae are thought to be close binary systems (ref. 1) involved in active mass transfer via Roche lobe overflow of matter from a late type star onto a white dwarf. An accretion disk is formed around the white dwarf as a result of the mass transfer

process and is predicted to contribute an appreciable fraction of the ultraviolet luminosity (ref. 2). The old novae V603 Aql (1918) and DQ Her (1934) were examined and their spectra are discussed in the context of the binary model.

The exact nature of the symbiotic variables has been an unresolved puzzle for many years. The optical spectra are usually dominated by a late-type giant and a strong nebular line spectrum, obscuring any contribution from a hot companion. The IUE data obtained for various of the symbiotics, however, show clear evidence for the existence of a hot component in many of these stars, supporting the binary hypothesis discussed in reference 3. Data for the spectroscopic binary AG Peg and the eclipsing system CI Cyg are presented as examples.

OBSERVATIONS

The low resolution ($\Delta\lambda = 5 \times 10^{-10} \text{ m}$) spectra were obtained with the short wavelength prime (SWP) camera of the IUE satellite on June 29 and December 14, 1979. The exposures were taken through the $10'' \times 20''$ oval aperture and were untrailed with the exception of SWP 7407 (AG Peg).

The data have been converted to absolute fluxes using the calibration given in reference 4. Unfortunately, the June spectra were processed using an incorrect intensity transfer function (ITF). However, additional spectra of similar quality for V603 Aql (SWP 5921) and CI Cyg (SWP 5485) have been processed using both the incorrect ITF and a corrected version (ref. 5). The average correction error between the two was 2.3%. Since the uncertainty in the absolute flux calibration of the SWP spectra longward of L_α ($\lambda 1216$) is estimated to be 10%, the results presented here would appear to be unaffected by the ITF problem.

The fluxes have been de-reddened using the reddening curve given in reference 6. The values of the color excess, $E(B-V)$, used to de-redden the data are indicated in each of the figures. The color excesses are small for the novae, tending to be larger for the more luminous symbiotic stars.

DISCUSSION

THE OLD NOVAE

The IUE data for V603 Aql are compared with earlier OAO-2 and ANS satellite measurements in figure 1. The satellite data have been de-reddened assuming $E(B-V) = 0.07 \text{ mag}$, as have the IUE fluxes. The systematic disagreement between the OAO-2 and IUE values shortward of $\lambda 1600 \text{ \AA}$ suggests real variability in the continuum of the hot component. The OAO-2 data were used (ref. 7) to derive ultraviolet colors and estimate a color temperature of 25,000 K. A hot model atmosphere ($T_{\text{eff}} = 25,000 \text{ K}$; $\log g = 4.5$) (ref. 8) is compared to the IUE data in figure 1 as well as the predicted flux distribution for an optically thick accretion disk ($f_\lambda \propto \lambda^{-2.33}$). Also shown are values from a white dwarf model

($T_{\text{eff}} = 25,000 \text{ K}$; $\log g = 8$) (ref. 9). The model fluxes have been normalized to the stellar fluxes at $\lambda 1700 \text{ \AA}$ where the continuum appears free of emission lines.

The continuum of DQ Her can be seen in figure 2 and offers a startling contrast to that of V603 Aql. It is well represented by a flux distribution of the form $f_{\lambda} \propto \lambda^0 = \text{constant}$ over the band-pass of the SWP camera ($\lambda \lambda 1200\text{--}1900 \text{ \AA}$). Despite the difference between the continua of the novae, however, the emission line spectra are qualitatively similar at least in the appearance of various of the lines. Note the strong NV ($\lambda \lambda 1239, 1243$) feature present in DQ Her which is absent from V603 Aql.

It is interesting to note that DQ Her is an eclipsing system seen at a relatively high inclination ($i \approx 70^\circ$) whereas V603 Aql is viewed nearly pole-on ($i \approx 15^\circ$). The difference in the appearance of the continua may thus reflect the differing aspects of these systems. Those binaries seen at high inclinations apparently must present a larger optical depth in the disk to the observer than do the lower inclination systems. This simple geometrical interpretation provides support for the models that posit the existence of optically thick accretion disks surrounding the hot white dwarf components.

THE SYMBIOTIC STARS

The IUE spectra of the symbiotic stars present a wealth of observational material. These data show a much richer and more diverse emission line spectrum than seen in the novae. Furthermore, the ultraviolet data provide direct confirmation, in many cases, of the existence of a hot companion. Spectra were obtained on two systems known to be binaries from optical studies. In figure 3 the low dispersion spectrum of AG Peg, a spectroscopic binary, is seen, and figure 4 presents a similar spectrum for the eclipsing system CI Cyg.

Satellite data also exist for AG Peg and are shown in figure 3 compared to the IUE fluxes after de-reddening using a value of $E(B-V) = 0.12 \text{ mag}$. Despite the large uncertainties associated with the earlier measurements ($\sim 34\%$ at $\lambda = 1330 \text{ \AA}$), the continuum appears to have systematically decreased by approximately 20% since the epoch of the OAO-2 observations (May 1970). Such a decline appears to be the source of the steady 0.025 mag/year decrease seen in the optical light curve which would also imply a 20% decrease in flux.

Model atmospheres from reference 8 were fit to the continuum of AG Peg and serve to provide an estimate of the temperature of the hot component ($T_{\text{eff}} \approx 40,000 \text{ K}$). This value is in accord with the temperature estimated from the OAO-2 measurements, discussed in reference 10.

Both the continuum and the emission line spectrum of the eclipsing system CI Cyg (figure 4) provide a marked contrast to those of AG Peg. The emission lines are much narrower and generally weaker. Note the presence of the strong permitted nitrogen lines in AG Peg and their weaker appearance or even absence in

CI Cyg.

Further support for the hypothesis developed above relating system inclination to continuum appearance is provided from the comparison of these two systems. CI Cyg appears at a very high inclination showing flat-bottomed eclipses of variable depth. AG Peg, on the other hand, is seen at a lower inclination of approximately 36° . Thus, the material (disk?) surrounding the high inclination systems would again appear to present a large optical depth to the line of sight. It is expected that spectra of the eclipsing nova T Aurigae and the other known eclipsing symbiotic star AR Pavonis would show similar effects.

CONCLUSIONS

IUE spectra have been presented for two old novae and for two of the symbiotic variables. Prominent emission line spectra are revealed as is a continuum whose appearance is effected by the system inclination. These data provide evidence for hot companions in the symbiotic stars, making plausible the binary model for these peculiar stars. It is also worthy to mention that recent IUE spectra of dwarf novae (ref. 11) provide additional support for the existence of optically thick accretion disks in active binary systems. The ultraviolet data of the eclipsing dwarf novae EX Hya and BV Cen appear flatter than for the non-eclipsing systems (e.g. VW Hyl), an effect which could be ascribed to the system inclination.

REFERENCES

1. Robinson, E. L.: The Structure of Cataclysmic Variables. *Ann. Rev. Astr. Ap.*, vol. 14, 1976, pp. 119-142.
2. Herter, T; Lacasse, M. G.; Wesemael, F.; and Winget, D. E.: Theoretical Photometric and Spectroscopic Properties of Stellar Accretion Disks with Application to Cataclysmic Variables. *Ap. J. Suppl.*, vol. 39, April 1979, pp. 513-535.
3. Boyarchuk, A. A.: Symbiotic Stars. Non-Periodic Phenomena in Variable Stars. Fourth Colloquium of Variable Stars, 1969, pp. 398-410.
4. Bohlin, R. C.; Holm, A. V.; Savage, B. D.; Snijders, M. A.; and Sparks, W. M: Photometric Calibration of the International Ultraviolet Explorer (IUE): Low Dispersion. NASA X-681-79-19, June 1979.
5. Cassatella, A.; Holm, A.V.; Ponz, D.; and Schiffer, F. H.: A Correction Algorithm for Low Dispersion SWP Spectra. NASA IUE Newsletter, No. 8, Feb. 1980, pp. 1-21.
6. Code, A. D.; Davis, J.; Bless, R. C.; and Brown, R. H.: Empirical Effective Temperatures and Bolometric Corrections for Early-Type Stars. *Ap. J.*, vol. 203, Jan. 1976, pp. 417-434.
7. Gallagher, J. S.; and Holm, A. V.: Ultraviolet Detection of the Nova Variables V603 Aquilae and RR Pictoris. *Ap. J. Lett.*, vol. 189, May 1974, pp. 123-126.
8. Kurucz, R. L.: Model Atmospheres for G, F, A, B, and O Stars. *Ap. J. Suppl.*, vol. 40, May 1979, pp. 1-340.
9. Wesselius, P. R.; and Kooster, D.: Effective Temperatures of Hot White Dwarfs. *Astr. Ap.*, vol. 70, Dec. 1978, pp. 745-750.
10. Gallagher, J. S.; Holm, A. V.; Anderson, C. M.; and Webbink, R. F.: Ultraviolet Photometry from the Orbiting Astronomical Observatory. XXXIII. The Symbiotic Star AG Pegasi. *Ap. J.*, vol. 229, May 1979, pp. 994-1000.
11. Bath, G. T.; Pringle, J. E.; and Whelan, J. A. J.: Spectrophotometry of Dwarf Novae in the Wavelength Range 1250 - 7500 A. *Mon. Not. R. Astr. Soc.*, vol. 190, Jan. 1980, pp. 185-194.

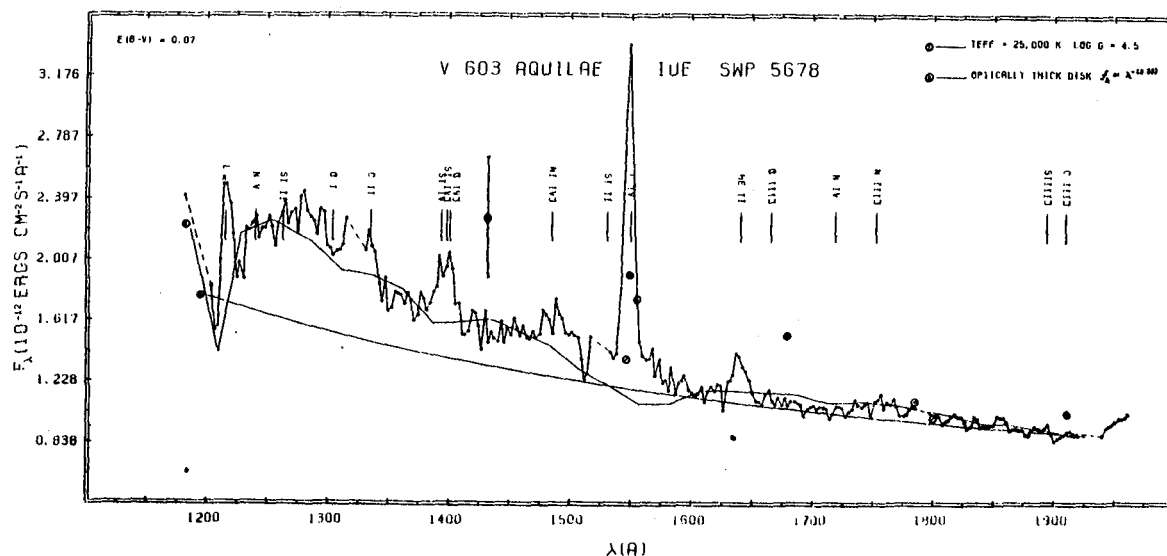


Figure 1 - The low-dispersion IUE spectrum for the old nova V603 Aql. The IUE fluxes are compared with the OAO-2 data (filled circles), the ANS data (open circles with dot), and the white dwarf model fluxes (circles with slash). Dashed regions of spectrum locate reseau contaminated portions. Also shown are the predicted fluxes of a stellar model atmosphere (O) and an optically thick accretion disk (Θ). See discussion in the text.

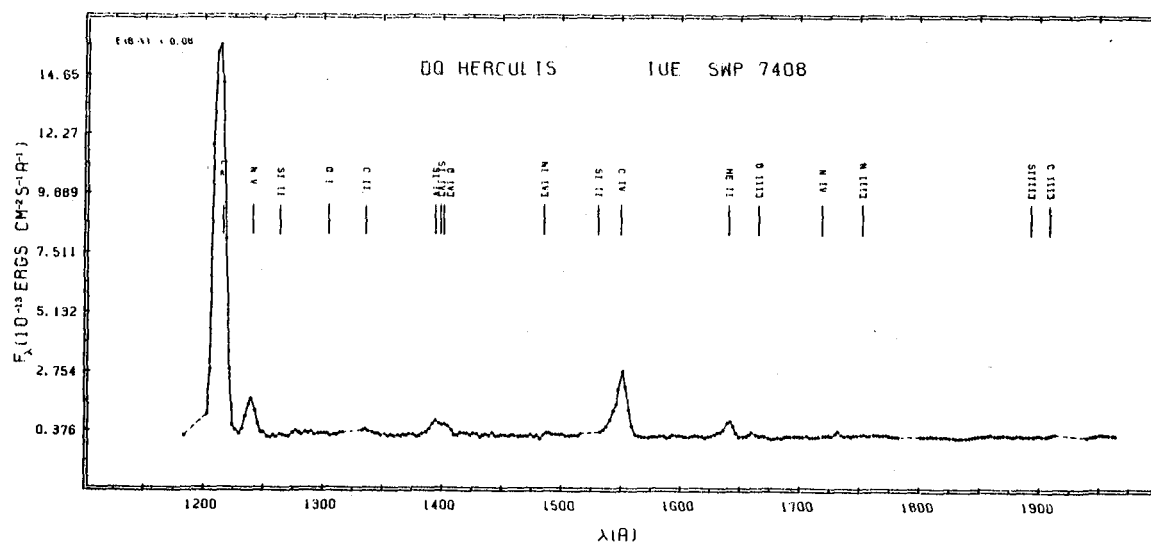


Figure 2 - As in figure 1 for the old nova DQ Her. The data have been de-reddened using a value of $E(B-V) = 0.08$ mag. The strong L_{α} feature is geocoronal in origin.

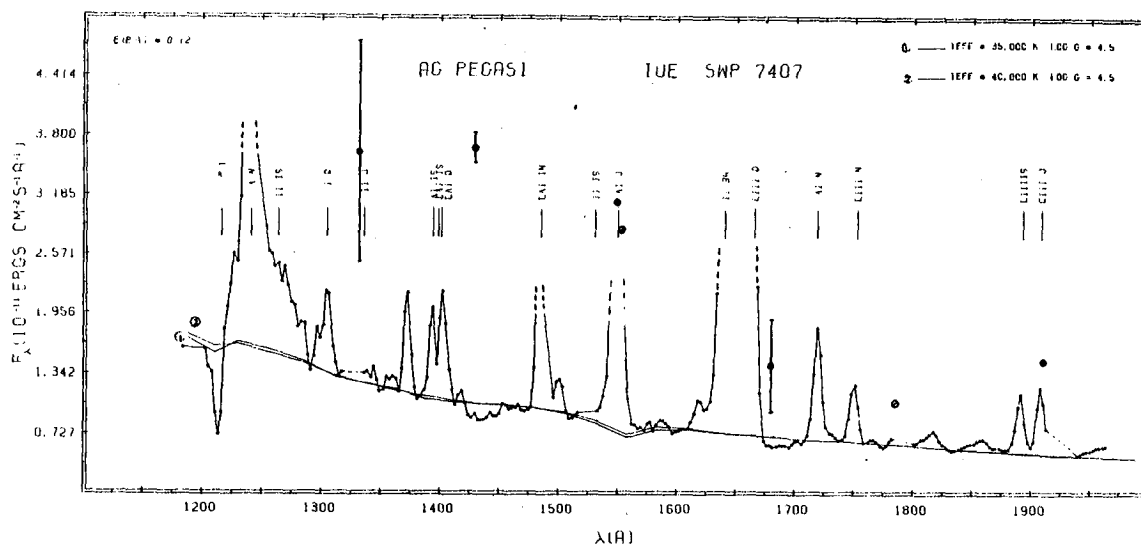


Figure 3 - Low-dispersion spectrum for the symbiotic variable AG Peg. The lines with dashed tops are saturated. OAO-2 data are represented by filled circles; ANS values by open circles with dot. Two model atmospheres are fit to the continuum: \odot - $T_{\text{eff}} = 35,000$ K and \ominus - $T_{\text{eff}} = 40,000$ K.

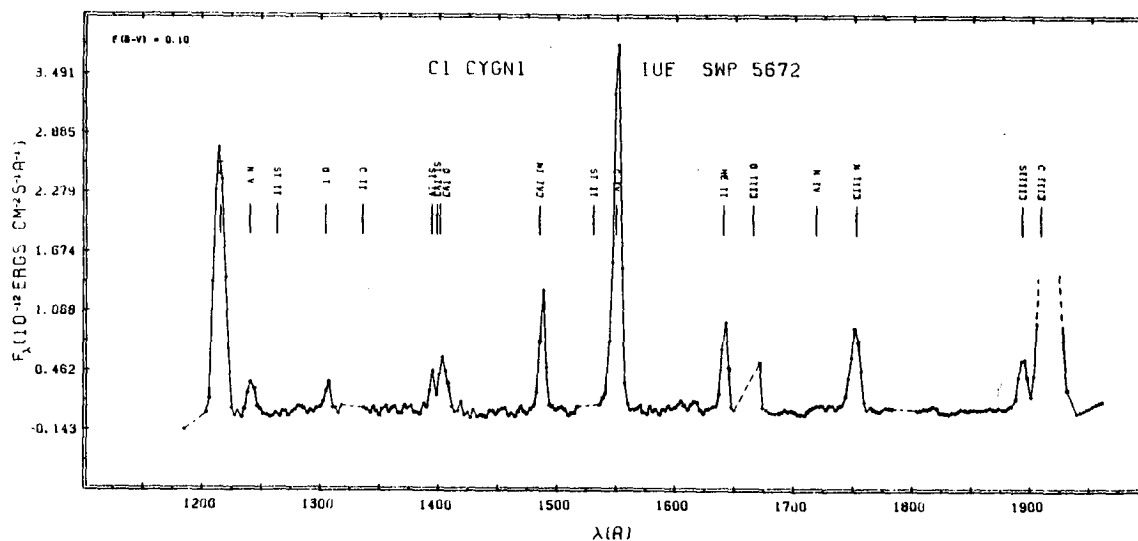


Figure 4 - As in figure 3 for the eclipsing symbiotic CI Cyg. The fluxes have been de-reddened using a value of $E(B-V) = 0.10$ mag.